UNITED STATES PATENT APPLICATION

of

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for a

POWER AMPLIFIER SYSTEM WITH MULTIPLE PRIMARY WINDINGS

BACKGROUND OF THE INVENTION

The invention relates to the use of power amplifiers, and particularly relates to using transformers to couple a power amplifier to a load.

Employing transformers to couple a power amplifier to a load generally permits any desired voltage transformation to be achieved within an operating range. Amplifiers with relatively small supply voltages may provide large voltage swings across the load. Moreover, transformers may act as impedance matching networks in certain applications to achieve maximum power transfer to the load.

As shown in Figure 1, a conventional power amplifier system employing a transformer to couple a power amplifier 10 to a load 12 involves a transformer 14 having a primary winding 16 and a secondary winding 18 that provides a turns ratio of *N:1* as indicated. Generally, the choice of *N* depends on the voltage and current requirements of the load, as well as the voltage and current ratings of the amplifier 10.

Although it is desirable to provide wide swings of output current for certain applications, a large turns ratio as well as large voltage swings are generally needed to provide the large output current. Further, systems that employ a large turns ratio to provide the high current (and power) output generally result in the generation of substantial heat that must be dissipated as evenly as possible, particularly if the system or circuit includes thermally sensitive components.

There is a need therefore, for an amplifier system that provides large current swings. There is a further need for such an amplifier system that reduces localized heating.

SUMMARY OF THE INVENTION

The invention provides a power amplifier system including a plurality of amplifiers, a plurality of primary transformer windings, a single secondary transformer winding. Each of the plurality of amplifiers includes a differential input that is commonly coupled to a system input port, and each the plurality of amplifiers also includes a differential output. Each of the plurality of primary transformer windings is coupled to the differential output of one of the plurality of amplifiers. The single secondary transformer winding is inductively coupled to all of the primary transformer windings and provides a system output port to which a load may be coupled.

BRIEF DESCRIPTION OF THE DRAWING

The following description may be further understood with reference to the accompanying drawing in which:

Figure 1 shows a prior art circuit diagram for a power amplifier circuit; and

Figure 2 shows a circuit diagram for a power amplifier circuit in accordance with an embodiment of the invention.

DETAILED DESCRIPTION OF THE INVENTION

The invention provides for the distribution of the primary current of a transformer among multiple windings. This reduces the need for a large turns ratio in the transformer. Instead of one single amplifier delivering all the current, multiple amplifiers are employed to deliver the required power to the load. Uniform spatial distribution of power amplification across the circuit chip also avoids localized heating and ensures that temperature sensitive components on the chip experience the same thermal effects and maintain good matching with other similar components.

As shown in Figure 2, a circuit in accordance with an embodiment of the invention provides *m* amplifiers 20, 22, 24 feeding *m* primary transformer winding 26, 28, 30 of the coupling transformer having a single secondary transformer winding 32. The turns ratio from each primary winding 26, 28, 30 to the secondary windings 32 is still *N:1* as discussed above with reference to Figure 1. Each of the amplifiers 20,22,24 includes a differential input 40,42,44 that is commonly coupled to a system input port 46, and each of the amplifiers 20,22,24 also includes a differential output 50,52,54. Each of the primary transformer windings 26,28,30 is coupled to the differential output 50,52,54 of the amplifiers 20,22,24. The single secondary transformer winding 32 is inductively coupled to all of the primary transformer windings 26,28,30 and provides a system output port to which a load 34 may be coupled.

As explained in more detail below, the current provided by each amplifier is $i_1 = i_2 / (mN)$ where i_2 is the current at the load 34. While the voltage and current swing requirements of each amplifier are maintained at $v_1 = Nv_2$. Each amplifier needs to provide only current i_1 where $i_1 = i_2 / (mN)$, which is *m* times smaller than the current in a single - primary system of Figure 1.

Further, since each primary winding current is m times smaller than the current in a single - primary winding system with a $Nm:1$ turns ratio, larger gauge (thinner) wires may be utilized in the primary, and as a result, the transformer may be made smaller in both size and weight.

In accordance with an embodiment of a system of the invention, an overall power amplifier may deliver high output currents using any number of two or more (m) weaker amplifiers that are coupled to the load with an m - primary transformer. Such a system that is configured with m power amplifiers may be formed using m output stages connected in parallel. These m output stages may be distributed spatially across a circuit chip to avoid localized heating and severe thermal gradient.

Further, the use of multiple (m) output stages, each having a quiescent current of I_Q, coupled through m primaries of a single transformer that is coupled to a load, can achieve higher phase margin and better stability. In particular, if there are m output stages each carrying a quiescent current of I_Q and each output stage is coupled to the load through one primary of an m - primary transformer, then each output stage faces a parasitic capacitance of C. On the other hand, if there is only one output stage carrying a quiescent current of mI_Q and this stage is coupled to the load through the single primary of a transformer, then the output stage drives a parasitic capacitance of mC. The transformer in the first case above isolates the output stages from each other at high frequencies and as a result, each output stage has to drive its own parasitic capacitance at the GBW frequency. In a CMOS amplifier, the gain (g_m) of the output stage improves with the square root of the quiescent current. The effective gain g_m of the output stage in the first case above, therefore, is $\sqrt{m}$ times lower than the effective gain g_m of the output stage in the second case above. Also, the non-dominant pole of the amplifier for the first case

above is 1/C, while that of the second case above is:

$$\sqrt{m}\Big/ mC = 1\Big/\sqrt{m}C$$

The non-dominant pole in the first case above, therefore, is $\sqrt{m}$ times higher than that of the second case above.

The above relationships may be shown by modeling an amplifier circuit of the invention with its Thevenin equivalent circuit comprising a voltage source v_S and a series resistor R_S. The current provided by the amplifier i_1 and the current flowing into the load is i_2 may be determined as:

$$i_2 = \frac{Nv_S}{N^2 R_L + R_S}$$

$$i_1 = \frac{i_2}{N}$$

When m amplifiers are used coupled through m primaries to the load as shown in Figure 2, the current flowing into the load may be defined as:

$$i_2 = \frac{Nv_S}{N^2 R_L + R_S / m}$$

$$i_1 = \frac{i_2}{Nm}$$

A comparison of the first and third equations above (for i_2) show that almost the same current that flows into the load for the circuit diagram shown in Figure 1 as flows into the load for the circuit of Figure 2. On the other hand, the second and fourth equations above (for i_1) show that the current provided by each amplifier in Figure 2 is m times smaller than the current provided by the amplifier in Figure 1. With the proper choice of N and m, therefore, both voltage

and current requirements of the load may be realized.

A transformer may saturate if magnetic flux density (B) in the core exceeds a maximum value, B_{MAX}. Magnetic flux density in the core is the time integral of the voltage across the secondary divided by the number of turns in the secondary by the core cross sectional area. By using the proposed idea of m primaries of Nm turns, the magnetic flux density and the saturation limit of the transformer are intact.

Mismatch in the turns ratio from one primary to the other has a minor effect in equal distribution of the current among the amplifiers. Assuming a turns ratio of $N_{Ii}:1$ (where I=1, … m), the current flowing in the load is:

$$i_2 = \frac{\overline{N} v_S}{\overline{N}^2 R_L + R_S / m}$$

where $\overline{N}$ is the average number of turn of the primaries of the transformer. Distribution of the current among m amplifiers is proportional to the number of turns in their corresponding primary winding. Mismatch in the number of turns of primaries, therefore, does not result in significantly different power dissipation in amplifiers and mismatched local heating.

Power amplifier systems of the invention may be used in a wide variety of applications, including DSL modems. For example, in the CPE ADSL modem, the line driver should provide power up to 12.5 dBm to a twisted - pair line with input impedances as low as $100\,\Omega$. Typically, a ± 12 v stand-alone bipolar line driver is used. Fabricating the line driver on the same + 5 v CMOS substrate beside the rest of the analog front end is not easily feasible because of the local heating effect due to the line driver and large parasitic capacitance loading on the output stage. Sourcing and/or sinking large currents at the output requires large output

transistors, which themselves contribute to large parasitic capacitance at the output. Such a driver requires a large secondary - to - primary turns ratio (e.g., as large as 2.5), which in turn leads to very large currents in the driver. The local heating due to this large current might lead to reliability issues and temperature gradient effects across the circuit chip. Taking advantage of the readily available two (or four) primaries of the hybrid transformer could lead to distribution of power among two (or four) amplifiers placed on two (or four) edges of the chip.

Those skilled in the art will appreciate that numerous modifications and variations may be made to the above embodiments without departing from the spirit and scope of the invention.

What is claimed is: